TRANSFORMER ARRANGEMENT FOR COMBINED POTS AND XDSL SERVICE

Field of the Invention

The invention relates to the field of plain old telephone services (POTS) and any type of digital subscriber loop (xDSL). More specifically the invention pertains to the transformers used in overlaid POTS and xDSL technology.

Background of the Invention

Digital subscriber loop (DSL) technology that offers the subscriber a very large bandwidth is engineered to overlay the existing analogue plain old telephone services (POTS). There are several types of DSL systems and the notation for specifying a DSL system of any type is xDSL. The xDSL system requires minimal equipment retrofit. It can be installed very quickly and easily, and is a cost-effective solution for high-bandwidth requirements. xDSL uses the existing copper analogue loop between the central office (CO) and the customer premises equipment (CPE) as its transmission medium, transporting voice in the traditional 4 kHz bandwidth where it has always been, while higher bandwidth digital services are relegated to higher frequency domains. A specific problem faced by overlaid POTS and xDSL technology, as well as other high-performance transmission systems, is the need to keep circuit costs low and packaging density high. Current technology makes use of a transformer for POTS and a second transformer for xDSL services in combination with a low pass filter (LPF) to combine POTS and xDSL services. The transformers have a significant volume and contribute significantly to the cost. Solutions for reducing the cost, volume and number of components in these circuits are therefore sought in the industry. Reducing the number of components also results in a reduction in inventory. In addition, due to the cost of real estate, an increased line

density is required and would result in most of the savings per line (per customer) by sharing common equipment costs among a large number of lines.

Summary of the Invention

The current technology involved with overlaying any type of digital subscriber loop (xDSL) services with plain old telephone services (POTS) makes use of two separate transformers, one for POTS and another for xDSL. In this invention the POTS transformer and the xDSL transformer are combined into one transformer. This is achieved by choosing a special geometric form for the core and by choosing strategic locations for the windings. A portion of the core is dedicated to serve as a shunt for each component of the magnetic field produced by the inductors. The geometric form of the core also provides a closed circuit of high permeability to restrict, to the core, the magnetic field produced by the current in the inductors. The windings of strongly coupled inductors are wound around the same portion of the core whereas the windings of weakly coupled inductors are wound around different core portions which are separated by the shunt. In overlaid POTS and xDSL applications a weak magnetic coupling between any one of the inductors used for POTS and any one of those used for xDSL services can therefore be achieved, despite their close proximity, by arranging the windings used for POTS and those of xDSL services around different portions of the core. Combining two transformers into one considerably reduces the weight volume and cost of the POTS + xDSL circuits.

In accordance with a first broad aspect, a transformer consists of a core formed by two coil portions, one central portion and connecting portions such that the central portion is spaced between the two coil portions and the

connecting portions interconnect both ends of the central portion with the corresponding ends of the two coil portions. There is at least one first primary winding and at least one first secondary winding wound around one of the two coil portions of the core. There is also at least one second primary winding and at least one second secondary winding wound around the other coil portion of the core. The central portion is adapted to provide a shunt for components of the magnetic field produced by electric current in the windings.

The transformer may have two first primary windings and one first secondary winding. It may also have two second primary windings and one second secondary winding. The turn ratio of either of the two first primary windings to the first secondary winding may be 1:1 and the turn ratio of either of the two second primary windings to the second secondary winding may be 1:1. The transformer may be connected such that the two first primary windings are connected to a capacitor and connected to two conductors of a copper analogue loop, which is used to connect subscriber customer premise equipment (CPE) to a central office (CO). The two conductors are referred to as TIP and RING. The two first primary windings and the capacitor may form a high pass filter (HPF) and the first secondary winding may be connected to any type of digital subscriber loop (xDSL) circuit. The two first primary windings may be connected to one side of a low pass filter (LPF). The two second primary windings may be connected to another side of the LPF and the second secondary windings may be connected to a plain old telephone service (POTS) circuit.

The core of the transformer may be iron, laminated iron, powdered iron, ferrite or any other suitable magnetic material.

The cross-sectional area of the central portion of the transformer, in relation to the cross-sectional of its coils and connecting portions, may be specified to regulate the extent to which components of the magnetic field produced by electric currents in the windings are shunted through the central portion. In this way the strength of the magnetic coupling between any one of the first windings and any one of the second windings can be tuned by controlling the extent to which the components of the magnetic field are shunted through the central portion.

Each portion of the transformer may be a rectangular parallelepiped. The approximate width, height and depth of the central portion may be 12 mm, 12 mm and 6 mm, respectively. The approximate width, height and depth of the coil portions may be 1.5 mm, 12 mm and 6 mm, respectively. Finally, the approximate width, height and depth of the connecting portions may be 3 mm, 1.5 mm and 6 mm, respectively. The magnetic coupling between any one of the first windings and any one of the second windings may be in the range 0.01 to 0.25, whereas the magnetic coupling between any two first windings or any two second windings may be in the range 0.9 to 0.9999.

An air gap may be inserted into the core between the first primary and secondary windings of the transformer and its thickness may be approximately 0.1 mm. A second air gap may also into the core between the second primary and secondary windings of the transformer and its thickness may be approximately 0.1 mm.

The invention makes use of a combined POTS and xDSL transformer to reduce the cost and volume of the overlaid POTS and XDSL circuits. The combined transformer results in a reduced inventory. In addition, the combined transformer allows

an increased line density which results in savings per line (per customer) by sharing common equipment costs among a large number of lines.

Brief Description of the Drawings

Preferred embodiments of the invention will now be described with reference to the attached drawings in which:

Figure 1 is a diagram of a typical electrical circuit which is used in overlaid plain old telephone services (POTS) and any type of digital subscriber loop (xDSL) services; and

Figure 2 is a transformer which combines two transformers of Figure 1, one for POTS and another for xDSL services, into a single transformer.

Detailed Description of the Preferred Embodiments

Figure 1 is a diagram of a typical arrangement of components which are used in overlaid plain old telephone services (POTS) plus any type of digital subscriber loop (xDSL) services. The arrangement of Figure 1 includes a transformer **10**. The transformer **10** consists of two first primary windings **20** and **30**, a first secondary winding **40** and a capacitor **45**. Traditionally, the two conductors of a copper analogue loop, which is used to connect the subscriber customer premise equipment (CPE) to the central office (CO), are referred to as the TIP and RING. Leads $\mathbf{A_{20}}$ and $\mathbf{B_{20}}$ of the first primary winding **20** are connected to the TIP and to a terminal $\mathbf{A_1}$ of a low-pass filter (LPF) **55**, respectively. Terminals $\mathbf{A_{30}}$ and $\mathbf{B_{30}}$ of the first primary winding **30** are connected to the RING and a terminal $\mathbf{A_2}$ of the LPF **55**, respectively. Terminals $\mathbf{A_{40}}$ and $\mathbf{B_{40}}$ of the first secondary winding **40** are connected to a xDSL circuit. The terminals $\mathbf{B_{20}}$ and $\mathbf{B_{30}}$ of the first primary windings **20** and **30**, respectively, are connected to the capacitor **45**.

Terminals A_3 and A_4 of the LPF **55** are connected to resistors **58** and **59**, respectively. The resistors **58** and **59** are connected to a transformer **85**. The transformer **85** consists of two second primary windings **50** and **60** and a second secondary winding **70**. The resistor **58** is connected to a terminal A_{50} of the second primary winding **50** and a terminal B_{50} of the second primary winding **50** is connected to ground. The resistor **59** is connected to a terminal A_{60} of the second primary winding **60** and a terminal B_{60} of the second primary winding **60** is connected to a CO (-48 V) battery **95**. Terminals A_{70} and B_{70} of the second secondary winding **70** of the transformer **85** are connected to the voice circuit of the CO.

Both POTS and xDSL signals are transmitted and received at the TIP and RING. The combination of the capacitor **45** and the first primary windings **20** and **30**, which operate as inductors, serve as a high pass filter for the high frequency xDSL signal. The first secondary winding **40** is used to couple the xDSL signal between terminals A_{20} and A_{30} of the first primary windings **20** and **30**, respectively, and terminals A_{40} and B_{40} of the first secondary winding **40**.

The LPF **55** connected to the terminals B_{20} and B_{30} of the first primary windings **20** and **30**, respectively, serves to transmit the low frequency POTS signal in the traditional 4 kHz channel bandwidth to its terminals A_3 and A_4. The resistors **58** and **59** are used to provide terminating impedance and a direct current (DC) loop current limit to the copper analogue loop and the LPF **55**.

The transformer **85** is used to provide a direct current (DC) to the copper analogue loop in addition to the POTS signal. The DC current is needed to operate a telephone set at the CPE. By connecting the terminal B_{50} of the second

primary winding **50** to ground and connecting the terminal $\mathbf{B}_{60}$ of the second primary winding **60** to the CO (-48 V) battery **95** a potential difference between the TIP and RING is created driving a component of current through the copper analogue loop. The second primary windings **50** and **60** and the second secondary winding **70** couple the POTS signal between the terminals $\mathbf{A}_{50}$ and $\mathbf{A}_{60}$ of the second primary windings **50** and **60**, respectively, and the terminals $\mathbf{A}_{70}$ and $\mathbf{B}_{70}$ of the second secondary winding **70**.

The POTS transformer **85** and the xDSL transformer **10** are in the same physical component. The POTS signal and the xDSL signal are isolated from each other because of a small magnetic coupling coefficient, k, between them.

Referring to Figure 2 which shows a transformer according to the invention, the transformer has a ferromagnetic core **10** which is rectangular in cross-section and is provided with two parallel rectangular holes **5** and **6** extending therethrough. It is convenient in describing the structure and operation of the transformer to refer to portions **11, 12, 14, 16, 17, 18** and **19** of the core. Portions **11, 12, 14, 16, 17, 18** and **19** are rectangular parallelepipeds. Portion **11** is a central portion or leg defined between the two holes **5** and **6**. Portions **12** and **14** are two marginal portions of the core **10** each defined by one of the holes **5** and **6** and one outside edge of the core **10**. Portions **12** and **14** may be referred to as coil portions because they are designed to carry windings or coils **20, 30, 40, 50, 60** and **70** which correspond to the windings **20, 30, 40, 50, 60, 70** shown in Figure 1. Thus coil portion **12** carries a first two primary windings **20** and **30** and a first secondary winding **40** and a coil portion **14** carries a second two primary windings **50** and **60** and a second secondary winding **70**. The coil portions **12** and **14** may also have optional air gaps **80**

and **90**, respectively. The air gaps **80** and **90** prevent magnetic saturation of the core **10** by the DC current.

Typical dimensions of the core **10** are 12 mm, 12 mm and 6 mm for the width (L), height (M) and depth, respectively. The holes **5** and **6** each have width (W) 3 mm and height (V) 9 mm. The central portion **11** has a width (X), height (M) and depth of 3 mm, 12 mm and 6 mm, respectively. The width (y_1), height (M) and depth of the coil portion **12** is 1.5 mm, 12 mm and 6 mm, respectively. The width (y_2), height (M) and depth of the coil portion **14** is 1.5 mm, 12 mm and 6 mm, respectively. The air gaps **80** and **90** are 0.1 mm wide. Portions **16, 17, 18** and **19** all have a width (Z_1), height (Z_2) and depth of 3 mm, 1.5 mm and 6 mm, respectively. The turn ratio of either first primary winding **20** or **30** to the first secondary winding **40** is 1:1. Similarly, the turn ratio of either second primary winding **50** or **60** to the second secondary winding **70** is 1:1. In another embodiment of the invention, portions **12** and **14** may have more than one secondary winding and the turn ratios between primary and secondary windings may be different than 1:1.

Each of the first primary windings **20** and **30,** the first secondary winding **40,** the second primary windings **40** and **50** and the second secondary winding **70** produces a component of the total magnetic field inside the core **10.** The set of first primary windings **20** and **30** and first secondary winding **40** produce magnetic field lines **100** and the set of second primary windings **50** and **60** and second secondary winding **70** produce magnetic field lines **110.**

The terminal leads **Ai** and **Bi** of winding **i** (where **i** = **20, 30, 40, 50, 60** or **70**) in Figure 2 correspond to the respective terminal leads **Ai** and **Bi** in Figure 1.

The first primary windings **20** and **30** and the first secondary winding **40** are used for xDSL and the second primary windings **50** and **60** and the second secondary winding **70** are used for POTS services. Together, they are used in overlaid POTS and xDSL applications. The first primary windings **20** and **30,** the first secondary winding **40,** the second primary windings **40** and **50** and the second secondary winding **70** are coupled to each other through the core **10.** In overlaid POTS and xDSL applications a strong magnetic coupling is required between any of the windings used for POTS. Similarly, a strong magnetic coupling is required between any of the windings used for XDSL. On the other hand, a weak magnetic coupling between any one winding used for POTS and any one winding used for xDSL is required. In the arrangement of Figure 1 the magnetic coupling coefficient, k, between any of the first primary windings **20** and **30** and first secondary winding **40** is between 0.9 to 0.9999. Similarly, the magnetic coupling coefficient between any of the second primary windings **50** and **60** and second secondary winding **70** is between 0.9 to 0.9999. This strong magnetic coupling is compatible with existing overlaid POTS and xDSL technology which uses two transformers in lieu of the combined transformer of this Figure. On the other hand, the magnetic coupling coefficient between any one of the first primary windings **20** and **30** and first secondary winding **40,** and any one of the second primary windings **50** and **60** and second secondary winding **70** is between 0.01 to 0.25. This weak magnetic coupling is low enough so that the signals (noise) due to the coupling does not affect the performance of the overlaid POTS and xDSL service.

The weak magnetic coupling between any one of the first primary windings **20** and **30** and first secondary winding **40** and any one of the second primary windings **50** and **60** and second secondary winding **70** is achieved despite the fact that they are in close proximity. The central portion **11** acts as a shunt for

the magnetic field lines **100** produced by electrical currents in the first primary windings **20** and **30** and the first secondary winding **40**. Similarly, the central portion **11** acts as a shunt for the magnetic field lines **110** produced by electrical current in the second primary windings **50** and **60** and the second secondary winding **70**. Since the magnetic field lines **100** and **110** are shunted through the central portion **11**, the magnetic flux through any one of the second primary windings **50** and **60** and second secondary winding **70** due to components of the magnetic field produced by any one of the first primary windings **20** and **30** and first secondary winding **40** is small. As a result the mutual inductance, and consequently the magnetic coupling coefficient, between any one of the first primary windings **20** and **30** and first secondary winding **40** and any one of the second primary windings **50** and **60** and second secondary winding **70** is low. On the other hand, the magnetic flux through a winding in portion **12** or **14** due to the component of magnetic field produced by a winding in the same portion is large and consequently the magnetic coupling coefficient is high.

The shunt effect can be understood from the reluctance of the circuit. The reluctance in a magnetic circuit decreases with decreasing length of the circuit, increasing cross-sectional area of the circuit and increasing permeability of the material. In Figure 2, a component of magnetic field produced by the first primary windings **20** and **30** and the first secondary winding **40** may follow a closed circuit through the central portion **11** or through the portions **19**, **14** and **18**. The cross-sectional of the central portion **11** is greater than that of the portions **19**, **14** and **18** and the length of a circuit through the central portion **11** is shorter than the length of a circuit through portions **19**, **14** and **18**. In addition, the presence of the air gap **90** also increases the reluctance of portion **14**. The reluctance of the central portion is therefore

much lower than that of the combined portions **19, 14** and **18,** and the air gap **90.** The lower reluctance of the central portion **11** results in the components of the magnetic field produced by the first primary windings **20** and **30** and the first secondary winding **40** to be shunted through the central portion **11.** Similarly, the lower reluctance of the central portion **11** compared to the combined portions **16, 12** and **17** results in the components of the magnetic field produced by the second primary windings **50** and **60** and the second secondary winding **70** to be shunted through the central portion **11.**

The overall effect of the geometric form of the core **10** is to shield the second primary windings **50** and **60** and the second secondary winding **70** from the magnetic field lines from the first primary windings **20** and **30** and the first secondary winding **40,** and vice-versa, to minimise the magnetic coupling coefficient, k, between windings of opposite sides of the core **10.** This is achieved despite the fact that the two sets of windings are in close proximity to each other.

In the preferred embodiment of the invention the cross-sectional area of portion **11** is chosen, in relation to other dimensions of portions of the core **10,** to shunt components of magnetic field through the central portion **11.** The result is a magnetic coupling coefficient between two windings wound around different coil portions of the core **10** in the range 0.01 to 0.25. In another embodiment, the cross-sectional area of portion **11** may be specified to tune the magnetic coupling coefficient from weak coupling to strong coupling. For example, reducing the cross-sectional area of portion **11** results in a decrease in the extent to which the components of the magnetic field are shunted through portion **11** and consequently the magnetic coupling coefficient between two

windings wound around different coil portions of the core **10** increases.

In the preferred embodiment of the invention, the core **10** is a rectangular parallelepiped. In another embodiment, the core and portions thereof may have different shapes as long as there is at least one shunt portion which can be used to shunt the magnetic field lines of the other portions. The specifications required to produce a shunt effect is a high permeability, short length and large cross-sectional area of the shunt portion.

The first primary windings **20** and **30**, the first secondary winding **40**, the second primary windings **40** and **50** and the second secondary winding **70** are oriented such that the magnetic field lines **100** and **110** are in opposite directions throughout the core **11**. The effect is to decrease the total magnetic field throughout the core **11**. In overlaid POTS and xDSL applications, the magnetising inductance of the first primary winding **20** when connected in series with the first primary winding **30** is approximately 2 mH. Since the turn ratio of the first primary windings **20** and **30** to the first secondary winding **40** is 1:1 the magnetising inductance of the first secondary winding **40** is also 2 mH. The magnetising inductance of the second primary winding **50** in series with the second primary winding **60** is approximately 100 mH. Therefore, since the turn ratio of the second primary windings **50** and **60** to the second secondary winding **70** is 1:1, the magnetising inductance of the second secondary winding **70** is also 100 mH. Since the magnetising inductance of the first primary windings **20** and **30** and the first secondary winding **50** is different than the magnetising inductance of the second primary windings **50** and **60** and the second secondary winding **70**, the magnitudes of the DC magnetic fields in portion **11** differ significantly. Therefore,

the effect of opposing magnetic fields on the total magnetic field is minimal in overlaid POTS and xDSL applications. As a consequence the effect of opposing magnetic fields on saturation in portion **11** is not very significant. While Figures 1 and 2 show one secondary winding for the xDSL circuit and one secondary winding for the POTS circuit it is known to those skilled in the art that there could be more than one secondary winding for xDSL and more than one secondary winding for POTS. In such a case in which portions **12** and **14** have more than one secondary winding, or if the turn ratios between the primary and secondary windings are different than 1:1, the effect of opposing magnetic fields on saturation in portion **11** may be significant.

When compared with the two transformers of POTS and xDSL in conventional overlaid POTS and xDSL arrangements, the single transformer in the arrangement of Figure 2 requires 22% less volume and the cost is reduced to 60%.

Numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practised otherwise than as specifically described herein.